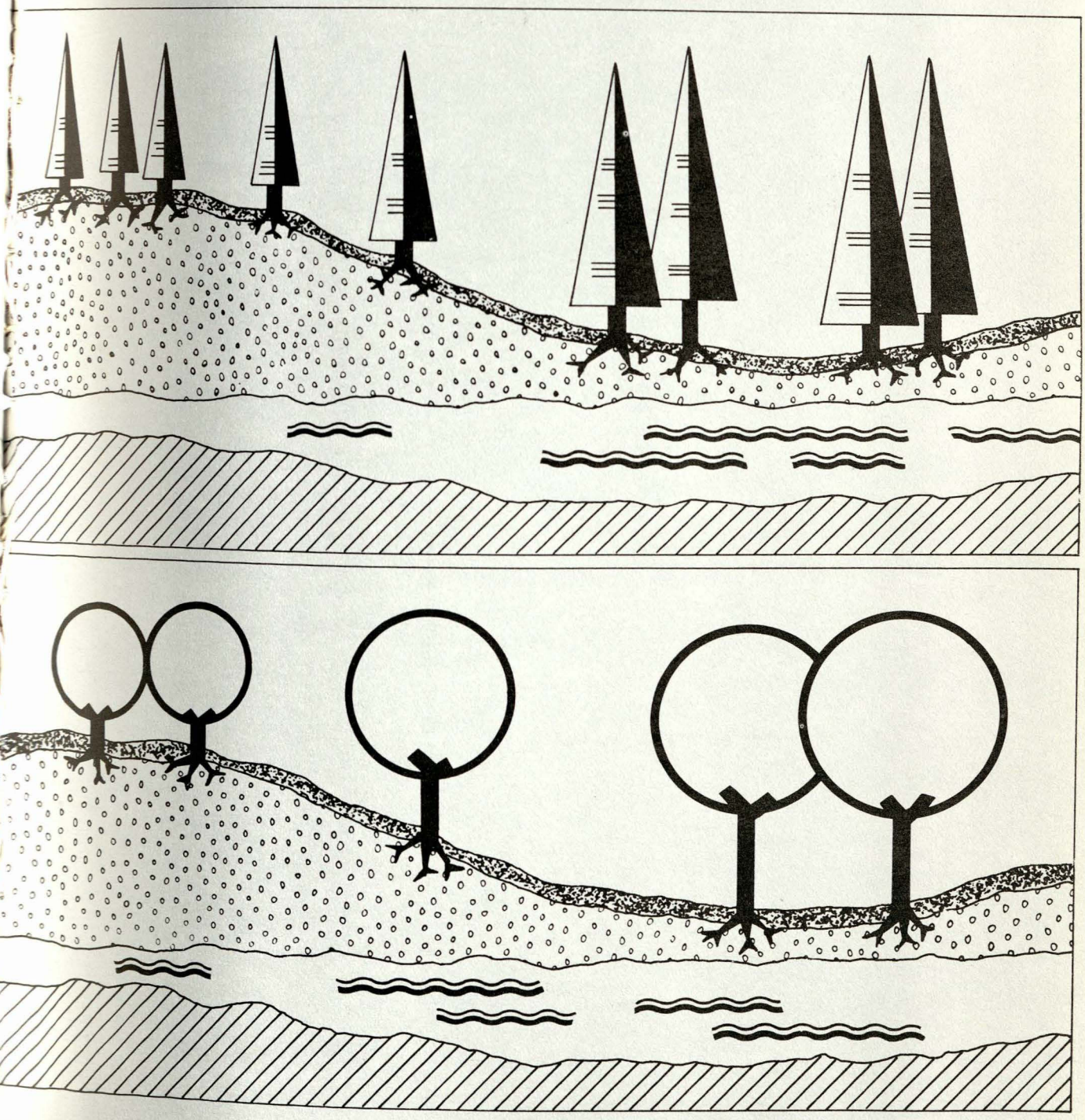
SDA FOREST SERVICE
ESEARCH PAPER NC-145

round water differences on PINE and HARDWOOD orests of the Udell Experimental Forest n Michigan.

DEAN H. URIE



RTH CENTRAL FOREST EXPERIMENT STATION
REST SERVICE

CONTENTS

	Page
Geology and Soils	1
Methods	5
Results	7
Discussion	12
Literature Cited	12

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service – U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108

Manuscript approved for publication December 9, 1976

1977

GROUND WATER DIFFERENCES ON PINE AND HARDWOOD FORESTS OF THE UDELL EXPERIMENTAL FOREST IN MICHIGAN

Dean H. Urie, *Principal Hydrologist*
East Lansing, Michigan

The Udell Experimental Forest was established near Manistee, Michigan, by the USDA Forest Service in 1959 as a field laboratory for studying the hydrology of forested glacial sand soils. One of the major objectives was to compare water yields from the primary forest cover types. Numerous reports have been published on changes in streamflow resulting from reforestation and cutting (Hibbert 1967). In our studies on the Udell, however, we used a new approach. We measured water yield from forested lands as increments of ground water recharge because of the extreme permeability of the soils in the Lake States sand drift area. Surface streams in the sand drift region usually drain large ground water basins that contain a variety of forest vegetation. In order to relate a specific type of vegetation to its hydrologic effects, we had to measure ground water recharge under different types of forest vegetation in a uniform ground water regime. The Udell Experimental Forest provided a variety of forest types in such a simple geologic situation. This report presents the results of 10 years of hydrologic measurements under jack pine *(Pinus banksiana)* and red pine *(P. resinosa)* plantations and under native hardwood forests typical of these sandy outwash plains.

GEOLOGY AND SOILS

The study area consists of sand outwash plains surrounding a sand moraine that resulted from the late Pleistocene (Valders) advance of continental glaciation about 10,000 years ago (Hough 1958). Terminal moraines of the Port Huron Substage were breached and reworked by this ice front and its recessional melt waters to form a large sand plain surrounding small morainal remnants, one of which is the upland known locally as the Udell Hills (fig. 1).

The Manistee and the Little Manistee Rivers flow westward to Lake Michigan through the sand plain. The Udell Experimental Forest lies between these two rivers. Small tributaries to the Little Manistee River form in high water table areas southeast of the Udell Hills. Pine and Claybank Creeks flow from the north side of the area and drain into the Manistee River. The pattern of water table levels shows that ground water flowing from the study area supplies these streams (fig. 2).

Upland soils are predominantly within the Grayling sand soil type, a Spodic Udipsamment. On some ridgetops in the morainal hills, a clayey sand subsoil within the surface 120 cm characterizes inclusions of the Graycalm series (Alfic Udipsamment). Shallow water table areas on the northwest and southeast boundaries contain the imperfectly drained Au Gres sands (Entic Haplaquod) and poorly drained areas contain Roscommon sand (Typic Aquipsamment) interspersed with woody Tawas histosols. Grayling sands cover more than 90 percent of the Experimental Forest.

The depth of the permeable sands was determined by drilling and by surface geophysical methods. Bedrock levels are 590 to 690 ft below the ground surface. Slowly permeable sandy-clay materials were located during drilling at an elevation of about 650 ft at two places on the east outwash plain (points A and B of fig. 2a). Clay surfaces were located at an elevation of 700 ft at two places on the northwest side of Udell Hills moraine (points C and D of fig. 2a).

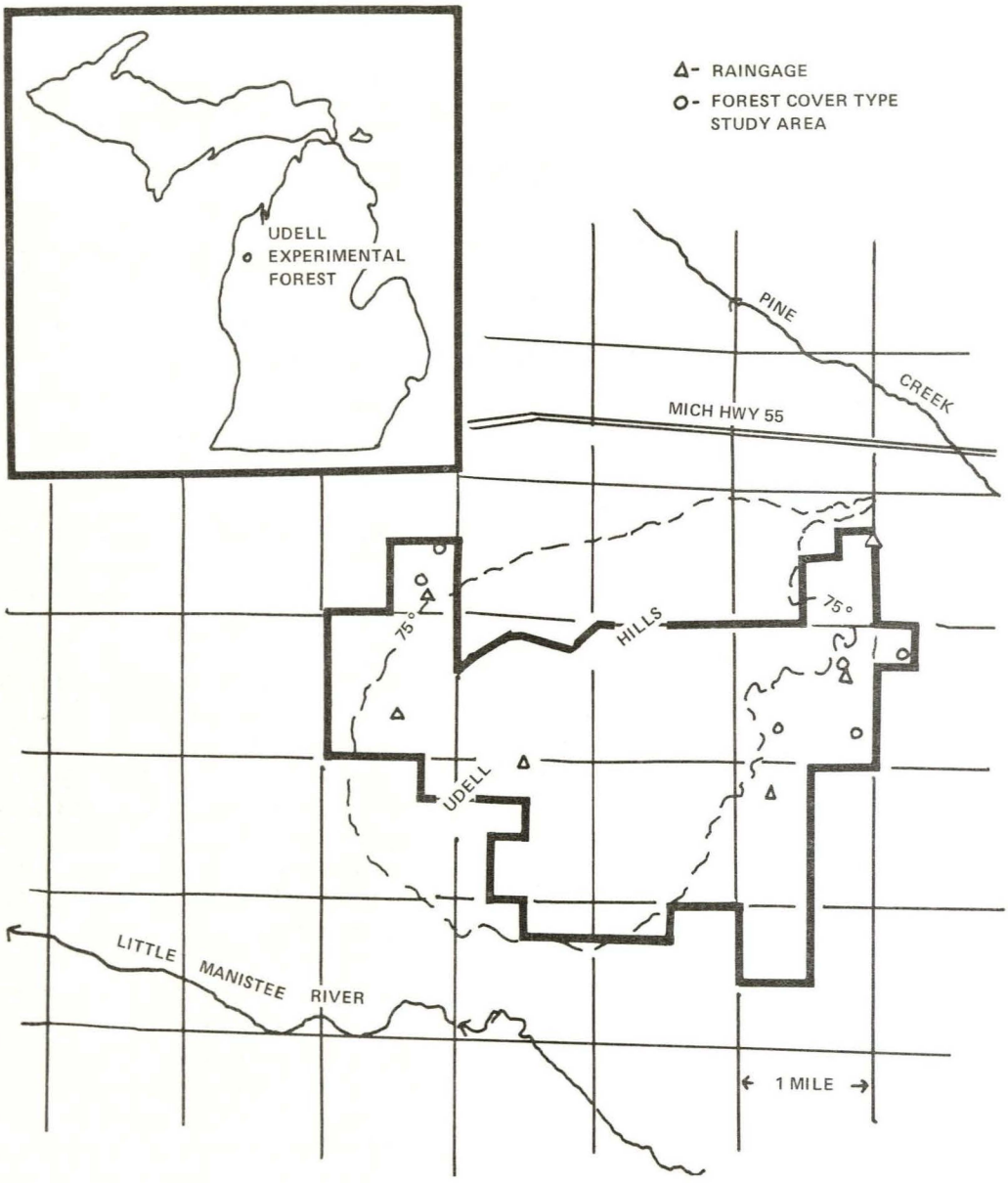


Figure 1.–*Location of Udell Experimental Forest, Manistee County, Michigan.*

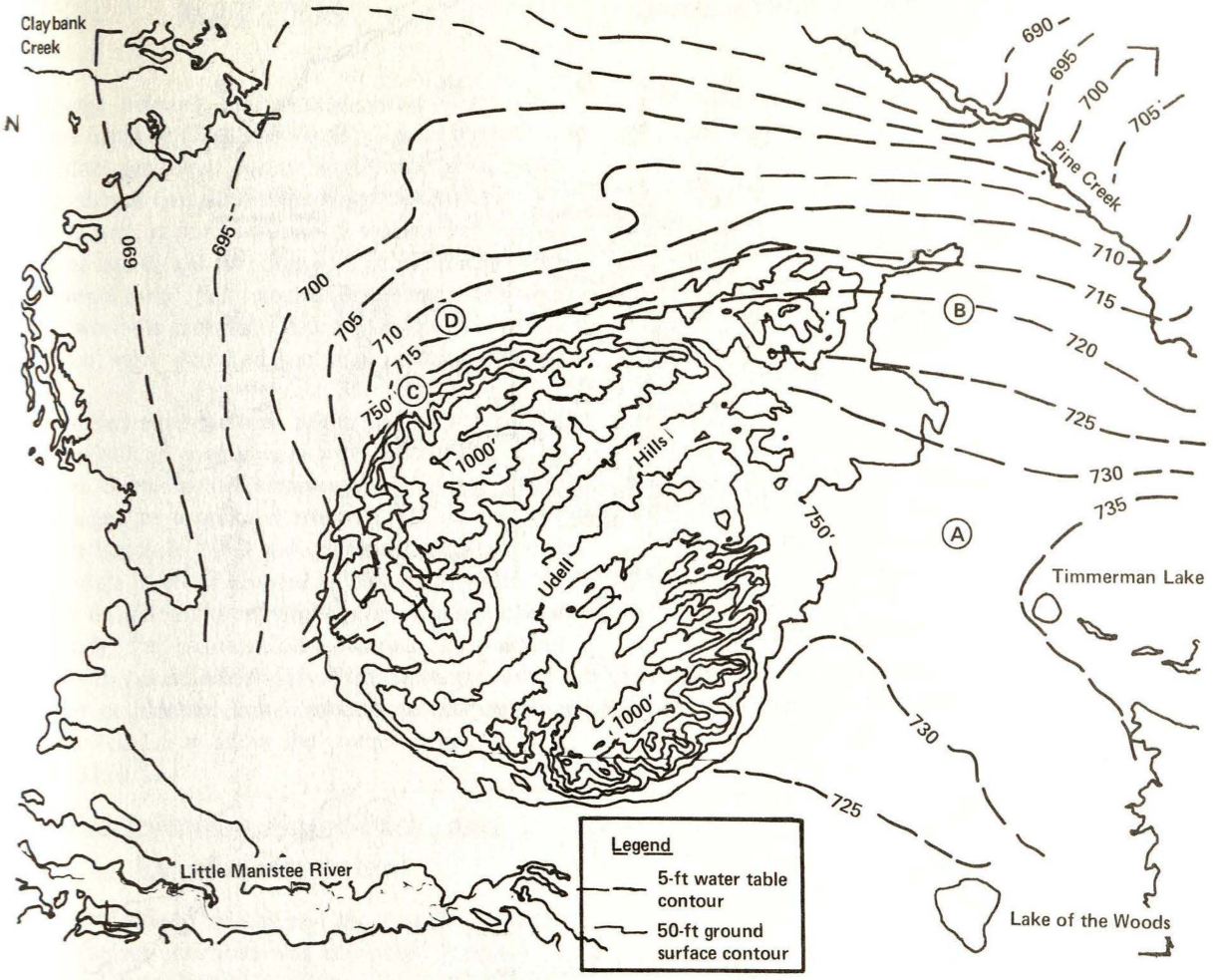


Figure 2a.—*Water table elevations of the Udell Experimental Forest.*

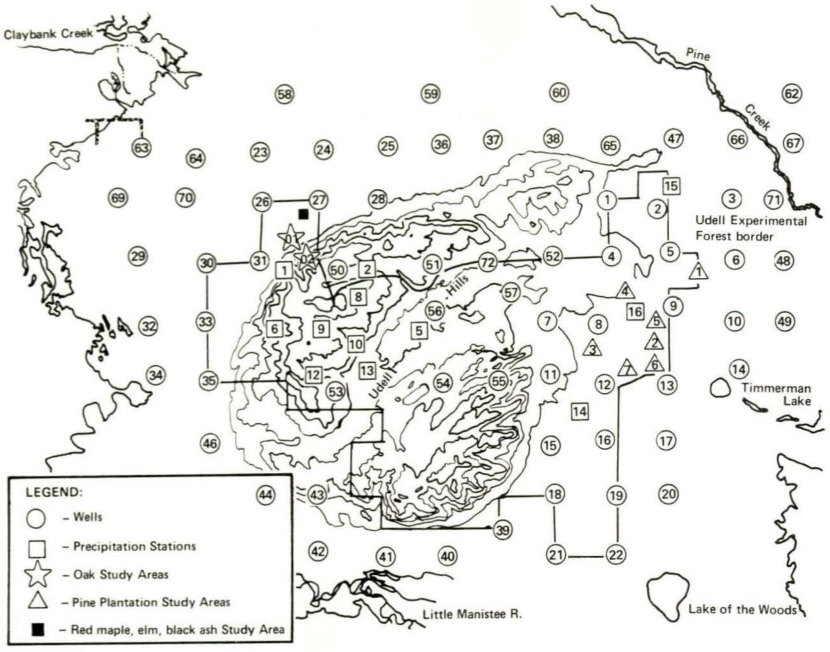


Figure 2b.–*Instrument and well locations of the Udell Experimental Forest. Well 63 is a 1/2-mile grid well net. Wells 45, 61, and 68 and precipitation stations 3, 4, 7, and 11 were never installed.*

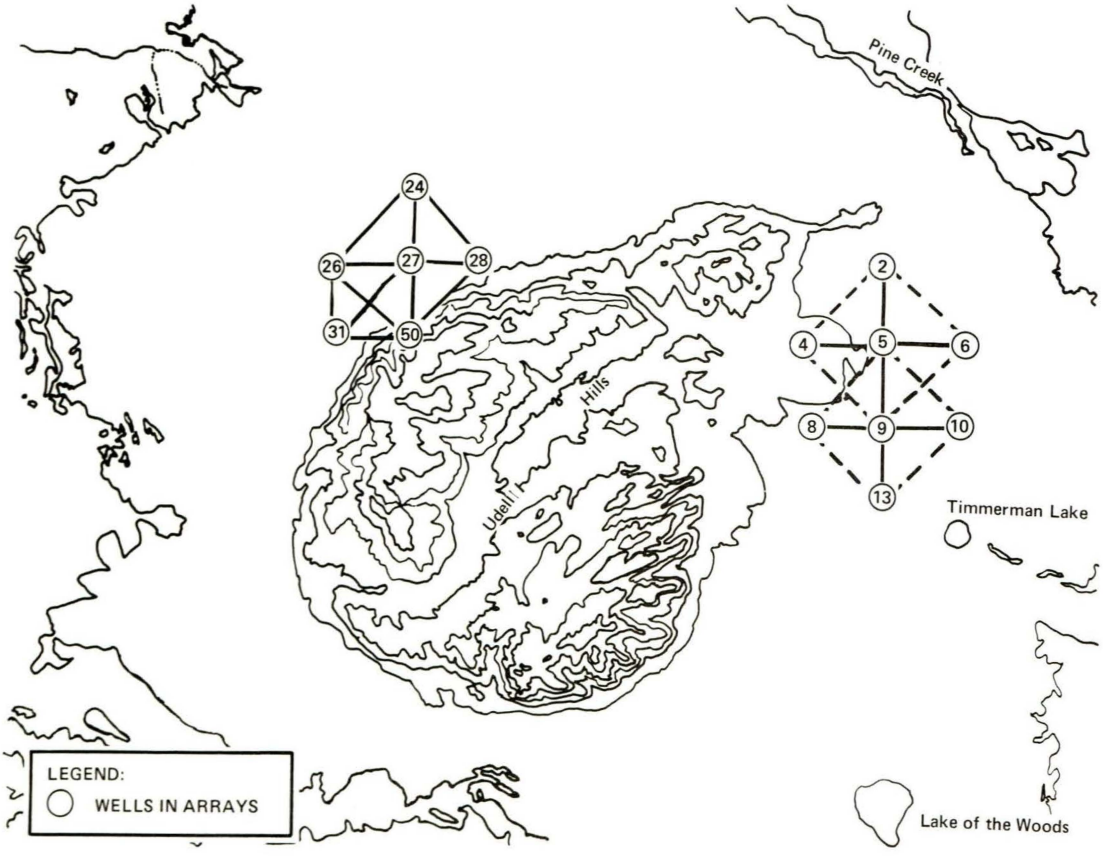


Figure 2c.–*Well arrays used for finite difference analysis of ground water budgets.*

METHODS

A raingage network and ground water observation wells were installed (fig. 2b). Water table measurements under native deciduous forests were made with water level recorders at two sites where water tables were at 21 to 24 m in oak, at one site in a 4.5 to 6 m well in oak, and at one site in a 0 to 1.5 m well in red maple. Well measurements under fully stocked pine plantations were made in two wells that had 4.5 to 6 m-deep water tables and in two wells that had less than 3 m-deep water tables.

These measurements were begun during the period 1959 to 1960 as instruments were installed and are continuing. Supplemental measurements in observation wells arranged in a grid pattern with 1/2 mi between wells were begun in 1960 and continued on a monthly basis through 1969. Snow pack information was obtained for deciduous forests and conifer plantations and subsequently for strip-cut and clear-cut plantations. Snow was measured with a Mt. Rose snow tube along five point courses. Measurements of air temperature were recorded 1.5 m above the ground at precipitation Station 15 (fig. 2b).

Precipitation, Snow-Pack, and Evapotranspiration

The mean value of rainfall and snow catch at the two nearest raingage locations was computed monthly for each ground water budget location.

Snow-pack water content estimates were computed from the mean of the five point snow course data measured on each date.

Estimates of monthly evapotranspiration and water yield were computed using the method of Thornthwaite and Mather (1957). Average precipitation from all gages on the Udell Experimental Forest and mean monthly temperature at Station 15 were used in this computation. Average soil moisture storage in the root zone was estimated to be 76 mm (3 in), for use in this calculation.

All hydrologic computations were summarized by water year (October 1 to September 30).

Ground Water Recharge from Precipitation

Water table elevations were used to compute ground water recharge from excess precipitation by two methods.

Diurnal Fluctuation Method

The analysis of changes in the volume of ground water as shown by water table changes was adapted from procedures developed by White (1932) as outlined by Urie (1966). The process involved three essential steps:

1. The ratio of the drainable pore space to the volume of aquifer dewatered was determined by draining soil columns removed from the zone of water table fluctuations and by relating the rise in water table to depth of rainfall during dormant season storms. The principal variables were time of drainage and depth of the aquifer layer below the soil surface. In comparison to these variables the differences due to particle size distribution were insignificant. For these analyses, gravity yield after 24-hour drainage in relation to depth was used for all wells (fig. 3).

2. The air trapped below a freshly saturated surface soil layer produces an exaggerated recharge pattern in the well record when water tables are 0.6 to 1.5 m below the soil surface (Meyboom 1967) (fig. 4a). This "Lisse effect" creates a problem of separating the well response due to percolating rainfall, which recharges the saturated

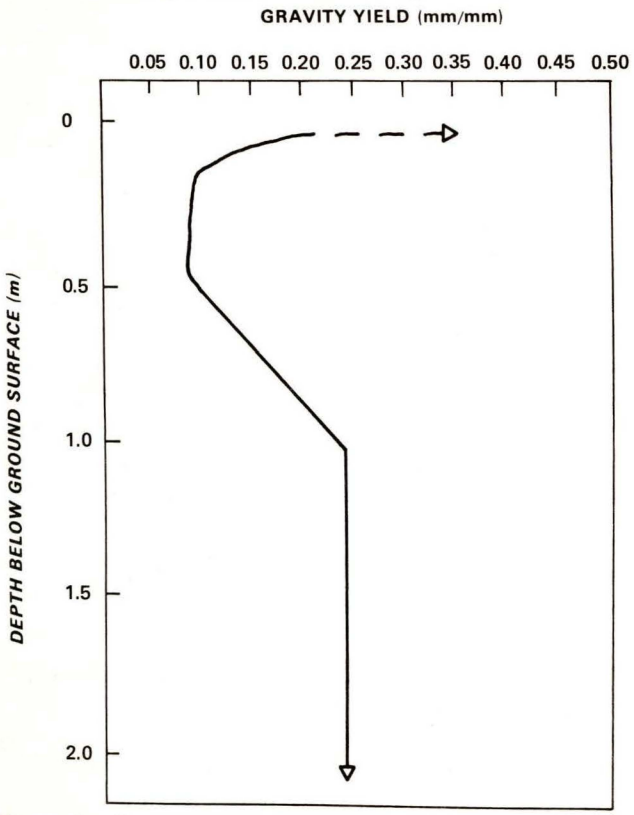


Figure 3.—*Gravity yield of surface aquifer sediments on the Udell Experimental Forest.*

zone. An empirical correction was used on the Udell well records by extending the pre-recharge recession curve 48 hours through the recharge event. Actual recharge due to percolating precipitation was computed from the departure of the well level above the projected recession curve.

When the water table depth is less than 0.6 m from the soil surface in these sand aquifers, the capillary zone extends to the surface and fills 90 to 95 percent of the drainable pore space. This greatly reduces specific yield. The so-called "Weiringermeer effect" is the result of a small amount of rainfall filling the few unsaturated soil pores and raising the piezometric surface as much as 18 times the amount of net rainfall (fig. 4b). Evaporation losses begin immediately after rainfall ceases, quickly removing readily available soil water. The well level recedes almost as quickly as it rose. These fluctuations were analyzed by applying appropriately small specific yield values when the water table was within 60 cm of the surface.

3. Water tables recede faster during daylight hours due to the upward capillary flow to replace evaporative losses in soil moisture. Graphical separation of the recession due to evaporation and that due to regional seepage flow to streams provided a measure of the evaporative demand of forests. These losses were analyzed for differences associated with water table depth, season, and forest cover.

Finite-Difference Analysis of Water Table Surface Method

Periodic measurements of the elevation of the water table for a fixed rectangular grid system of wells were used to compute a pattern of ground water seepage. Changes in well levels for the period were interpreted by use of the gravity yield estimate to compute periodic accretions to the zone of saturation due to vertical movement through the unsaturated zone. The method suggested by Stallman (1956) and used in Colorado by Weeks and Sorey (1973) has been described for the Udell Experimental Forest (Urie 1971). In the present study, data from wells arranged in a grid with 1/2 mi between them were utilized to produce an annual pattern of potential for ground water flow to streams. Annual runoff (ground water yield) values were computed using the sum of periodic products of runoff potential multiplied by the permeability of the aquifer. Aquifer permeability was determined from dormant season estimates of ground water discharge to streams. Annual changes in water table depth, at the end of each water year, weighted by appropriate specific yield values, were added to complete the recharge estimate. An example of these computations at well G-5, which is representative of deep water table pine forest, is shown in table 1.

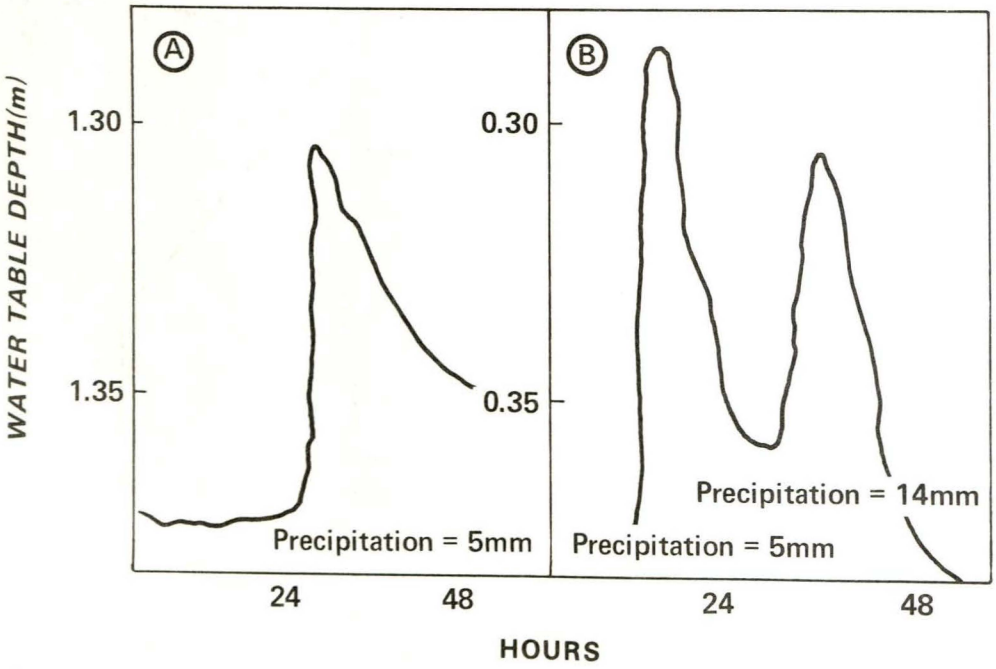


Figure 4.—*(a) Entrapped air "Lisse" effect on well level; (b) rapid well fluctuation near ground surface "Weiringermeer" effect.*

Table 1.–*Computation of annual ground water recharge (water yield), from a pine plantation on a well-drained site for the 1965 to 1966 water year*

Measurement date	$\nabla^2(h^2)$[1] X10-4	Average $\nabla^2(h^2)$ period	Days between measurements	ROgw[2]	ROgw
			Number	*mm/day*	*mm/period*
9/02/65	-1.01				
10/08/65	-0.97	-0.99	8	-1.29	-10
11/05/65	-0.99	-0.98	28	-1.27	-36
12/22/65	-0.48	-0.73	47	-0.95	-45
1/14/66	-0.62	-0.55	23	-0.72	-16
2/15/66	-1.14	-0.88	32	-1.14	-36
3/16/66	-1.34	-1.24	29	-1.61	-47
4/15/66	-1.18	-1.26	30	-1.64	-49
5/25/66	-1.12	-1.15	40	-1.50	-60
7/20/66	-1.15	-1.14	56	-1.48	-83
8/18/66	-1.16	-1.16	29	-1.51	-44
9/15/66	-1.14	-1.15	28	-1.50	-42
10/13/66	-1.17	-1.16	15	-1.51	-23
Total			365		-491

Correction for annual change in Aquifer Storage:

Annual ROgw (net) (mm) = ROgw - $\Delta h Y_g$
where h = annual change in water table elevation
Y_g = specific yield = 0.233
= -491 - (-30-0.233) = 484 mm

[1] $\nabla^2(h^2)$ = Finite difference estimate of ground water outflow potential. (h = annual change in water table elevation.)

[2] ROgw/day = $\frac{P}{2} \nabla^2(h^2)$ = daily outflow of ground water (mm)
P = 26,000 mm/day = effective permeability from solution of ROgw = $\frac{P}{2}$ x $\nabla^2(h^2)$ where W = recharge from Q pt. when W = 0

RESULTS

Precipitation: The period from 1960 to 1971 included three cycles of wet and dry years (fig. 5a). Well records, which began in 1960, illustrate the high levels of ground water that resulted from a 1958 to 1960 moisture excess.

The period from 1961 to 1963 was generally dry (840 and 764 mm annual rainfall, respectively). Precipitation increased in 1964 and 1965 to 914 and 1,029 mm, respectively. In September of 1965 236 mm of rain sent well levels up in advance of the normal dormant season recharge cycle.

Precipitation in the 1966 water year was the lowest of the period but the hydrological effects were moderate because both the preceding and the following years were the wettest in the decade. The driest period occurred during the summer months, when little ground water recharge occurs even in wet years, thus reducing the effect on ground water levels. In 1967, heavy fall and spring rains resulted in high water yields. Annual precipitation was at or below normal from 1968 through 1971. Extensive rainfall (221 m) in June 1969, produced a rare mid-growing season recharge.

Ground water in relation to water table depth and basin location: Characteristic levels for wells in deep (>15 m), medium (3 to 15 m), and shallow (<3 m) water table situations are shown in figure 6. The swamp well (G-27) showed little carry-over effect from hydrologic conditions of the previous year. The water level follows an annual cycle that has its maximum at the level where surface flooding begins and its minimum at the lowest depth of evaporation drain (about 1.2 m below the surface). Heavy rains frequently produce recharges.

Wells with overburden depths of from 3 to 15 m (G-5) have definite annual cycles of recharge and discharge. The hold-over effect of antecedent conditions is more evident in wells farthest from the stream. It is this reserve storage in the upper basin aquifer that supplies ground water to stream flow during prolonged drought periods. Ground water flow from such extensive aquifers produces the regular streamflow levels characteristic of sand drift region streams (Velz and Gannon 1960).

Well G-50, which has 70.5 m of unsaturated overburden sediments above the water table, showed the greatest time lag in ground water level response to available recharge. Excess moisture in 1967 produced the water table elevation peak in mid-1968.

Well levels were analyzed for the following six hydrologic relations on October 1 of each year from 1961 to 1971 (fig. 6b):

x_1 =precipitation during the previous water year,

x_2 =cumulative departures of precipitation from the 12-year average generated from Udell Experimental Forest data,

x_3 =cumulative 3-year departures from the 12-year average of precipitation,

x_4 =annual runoff (water yield) computed from monthly precipitation and mean temperature using Thornthwaite's method,

x_5 =cumulative departures of annual runoff from 12-year average of x_4,

x_6 =cumulative 3-year departures of annual runoff from the 12-year average of x_4.

Correlation coefficients ranged from 0.64 to 0.95 for the September 30 water table levels in 13 of the wells arranged in a grid. The wells were selected to represent a range of water table depths from <1 m to 10 m. Distance from influent streams ranged from 1.1 to 3.7 km.

Wells furthest from the streams, which also were those with the deepest overburden, were most highly correlated with X_6 (r = 0.86 to 0.95). Well levels closer to the drains, but still with water tables 2 m deep, were

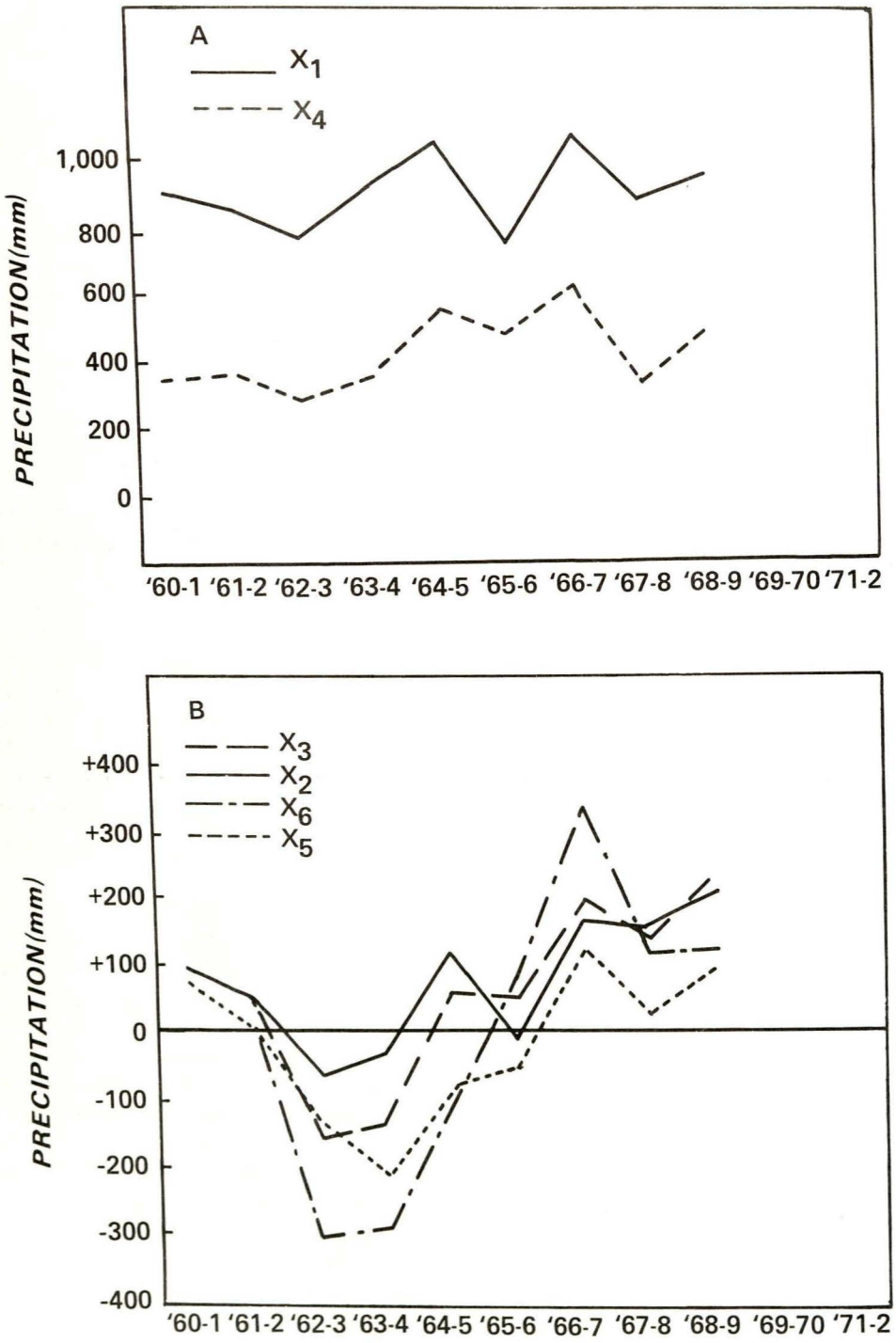


Figure 5.—*Patterns of climatic variables used for analysis of annual water table levels. The patterns of monthly precipitation and runoff were computed from monthly Thornthwaite estimates (Thornthwaite and Mather 1957) (x_1 = annual precipitation; x_2 = 3-year departures of precipitation; x_3 = annual departures of precipitation; x_4 = annual runoff; x_5 = departures of annual runoff; x_6 = 3-year departures of annual runoff).*

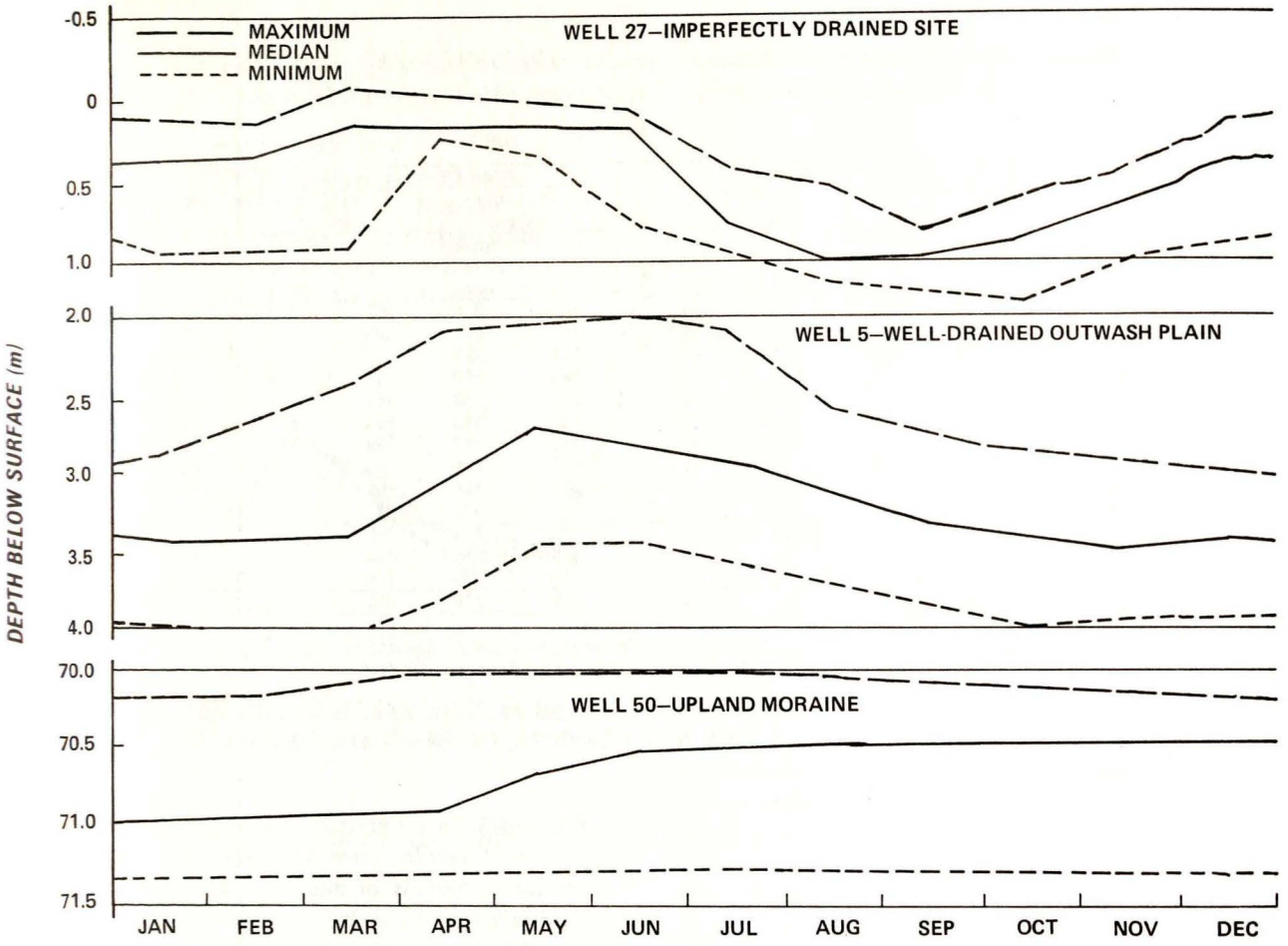


Figure 6.–*Maximum, minimum, and median monthly water table levels at three wells.*

most closely related to X_3. Well levels in shallower water table zones were related to X_1 and X_2 more closely than any other feature tested.

From this analysis it was apparent that ground water levels in deep lying water table aquifers–remote from streams and isolated from the evaporative drain that occurs from shallow water table areas in the immediate vicinity–are closely related to the cumulative water yield computed from climatic data. In this calculation a soil moisture storage buffer is used to balance between wet and dry years.

Shallow water table areas are most responsive to current precipitation and are related to both annual precipitation and cumulative departures from normal precipitation. Soil moisture storage has little effect on water table levels because upward capillarity maintains moisture in the unsaturated zone most of the year.

Water table levels in intermediate zones, which are affected by nearby shallow water table levels, were about equally related to the two measures of precipitation departures from normal (X_2 and X_4).

Comparisons of water yield by cover type: Two alternative uses of sand plain forest lands (native deciduous forests and pine plantations) were compared for water yield characteristics. The most consistent difference was a higher water yield under the deciduous forests on well-drained sites. A less consistent difference was found between the two cover types on shallow water table lands. In 1967, water tables were extremely high, local flooding in two of the shallow water table plots effectively short circuited the ground water flow system. Accordingly, data for this period were dropped from all comparisons between shallow water table forests.

The net monthly and annual recharge of ground water under the four cover-water table depth conditions were analyzed both graphically and by finite difference methods. Annual water yields were computed from October 19, 1961, to September 30, 1971 (table 2).

Table 2.—*Annual water yield estimates (ground water recharge) by forest cover, soil drainage classification, and method of computation (1961 to 1971)*
(In mm)

Water year	Hardwoods				Pine Plantations				Thornthwaite estimate (76 mm)
	Imperfectly-drained		Well-drained		Imperfectly-drained		Well-drained		
	Graph	Finite difference	Graph	Finite difference	Graph	Finite difference	Graph	Finite difference	
1961-1962	327	397	426	457	345	244	367	379	368
1962-1963	374	254	336	423	287	172	293	103	292
1963-1964	469	394	389	403	354	225	338	232	356
1964-1965	557	509	519	574	545	380	502	455	551
1965-1966	394	447	463	528	273	239	364	484	483
1966-1967	[1]620	[1]480	527	664	[1]520	[1]353	504	627	610
1967-1968	434	442	361	528	412	297	309	411	330
1968-1969	473	448	392	523	417	399	353	537	488
1969-1970	311		404		348	345	302		399
1970-1971	343		381		341	380	355		470
10-yr mean	430		421		384	303	369		435
9-yr mean[1]	409		409		369	298	354		415
8-yr mean	456	421	428	512	394	289	379	415	435
7-yr mean[1]	433	413	414	491	376	279	361	384	410

[1] Water year estimates for 1966 to 1967 were dropped from computation due to uncertainty of prolonged flooding effects on imperfectly-drained sites.

Cover type comparisons by either computation method for deep water table areas show that water yield is consistently higher under hardwoods. However, net recharge values in the shallow water table wells (less than 1.5 m) appear to be erroneously high in some years when computed graphically. The net recharge estimate was sometimes greater under shallow water table conditions than it was in the well-drained soils. Because of the high evaporation rate associated with shallow water table lands, these results are obviously in error. As determined in other studies, the finite difference method is more reliable for use in shallow water table conditions (Urie 1971). Therefore, the finite difference values should be used when comparing between cover types.

On well-drained lands that had water tables below the root zone throughout the year the mean water yield under oak was 512 mm (20.2 in), which is 97 mm (3.8 in) more than the mean water yield under pine plantations (finite difference method, 8-year average). Differences between cover types were greatest during the dry years (1963, 1964, and 1968) apparently because of the longer evaporative period in conifers that reduces autumn recharge.

The differences in annual ground water recharge patterns were illustrated by mean monthly ground water increments under the two cover types (fig. 7). Autumn recharge under leafless hardwoods exceeded recharge under pine forests.

A comparison of the hardwood and pine forests on imperfectly drained soils showed a reduction of 32 percent in water yield under pine (413 mm/year for hardwood vs. 279 mm/year for pine).

Snow pack measurements were analyzed to show the influence of conifer crowns in reducing water equivalents during periods of maximum snow accumulation. Snow melted earlier under hardwoods and produced an earlier rise in water tables (fig. 8). Because of this earlier melting under hardwood, the increased ground water recharge due to snow pack differences are spread through March and April and are not evident in figure 7. Daily accretions to ground water recharge during the 1963 melt period are shown in figure 9 for shallow water table pine and hardwood forests. Early melting under the open hardwoods resulted in earlier ground water recharge. Midwinter melt periods often reduce snow pack under hardwood forests, thus spreading the recharge period throughout the winter.

Hardwood forests on the Udell Experimental Forest are found on areas where water tables are high during the early summer. On these sites nearly one-half of evapotranspiration was supplied from the saturated zone. Pine plantations on shallow water table lands were near flood stage in the spring. However, water table depths during summer months under pine were lower than in the "shallow hardwoods". Only about 20 percent of evapotranspiration was supplied to the pine areas from the saturated zone. Because of the different hydrologic positions, cover type differences could not be entirely separated from site.

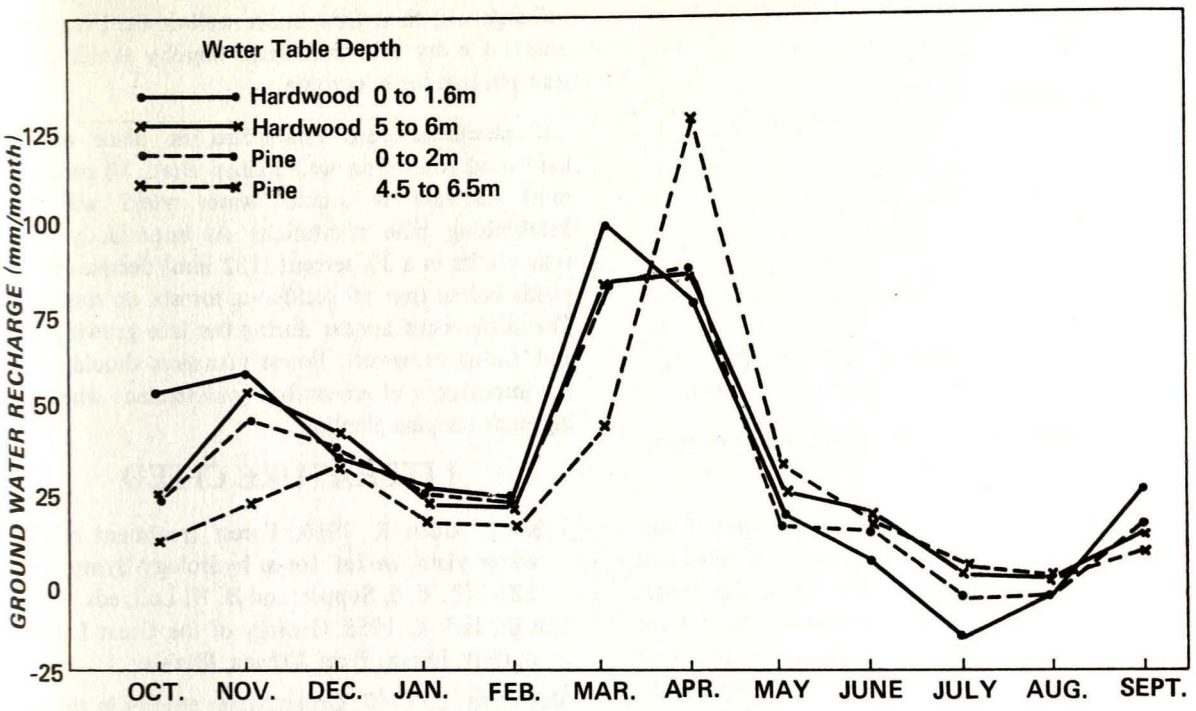


Figure 7.–*Ten-year average monthly ground water recharge by cover type and water table depth.*

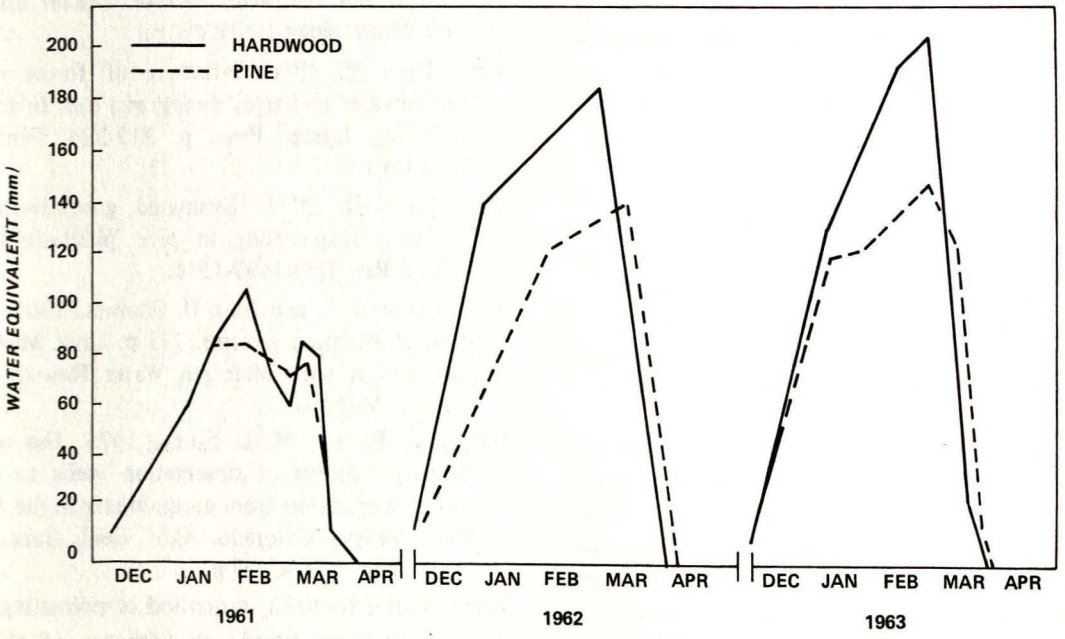


Figure 8.–*Effects of forest cover on snowpack water content, 1961-1963.*

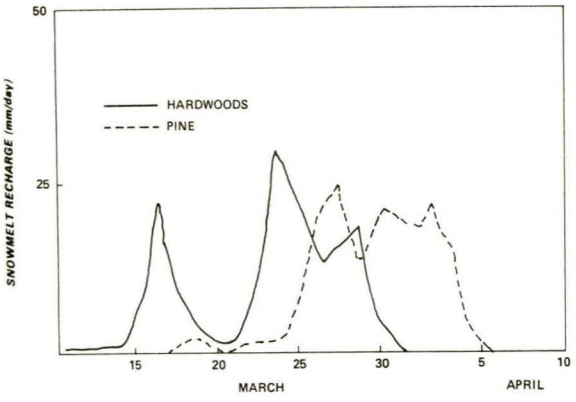


Figure 9.—*Snowmelt effects on ground water recharge, 1963.*

Effects of water table depths on water yields: Comparisons of annual water yields between well-drained and imperfectly-drained sites were made using the finite-difference analyses method. Comparable data were available for 7 water years. Both pine and hardwood forests had lower water yields on the imperfectly drained sites than on the well-drained upland soils. Upland oak forests yielded an average of 491 mm (19.3 in) of water for the 7 years. In a neighboring red maple-elm-black ash forest on imperfectly drained soils the water yield was 16 percent less (413 mm (16.3 in)).

A similar comparison for pine plantations for the same period gave water yield estimates of 384 mm (14.8 in) on well-drained sites. On imperfectly drained lands the same pine species at similar ages yielded 26 percent less annual water yield (279 mm (11.0 in)).

DISCUSSION

Watershed problems in sand drift areas, such as represented by the Udell Experimental Forest, are generally those due to droughty soils and surface instability. These sand areas perform almost ideally as drainage basins. Approximately 50 percent of the annual precipitation is yielded to streams in the form of evenly distributed ground water flow.

The history of Udell ground water behavior illustrates the influence of forest cover on the volume of water produced from a typical sand drift forest area. These records have provided some insights into the location within a ground water basin where forest cutting may result in additional water for augmenting streamflow during prolonged dry periods. Efforts to increase base flow should be made in well-drained lands in the portion of the basin furthest from the streams. Ground water recharge will then flow under well-drained lands to its point of entry into the stream thereby avoiding evapotranspiration losses enroute.

If plantations are established in place of native hardwood forests on well-drained sites, 18 percent (97 mm) decrease in annual water yield will result. Establishing pine plantations on imperfectly drained soils results in a 32 percent (132 mm) decrease in water yields below that of deciduous forests on similar sites. The differences appear during the late growing season and during snowmelt. Forest managers should consider the importance of streamflow maintenance when selecting lands for pine plantings.

LITERATURE CITED

Hibbert, Alden R. 1966. Forest treatment effects on water yield. *In* Int. forest hydrology Symp. Proc. p. 527-543. W. E. Sopper, and H. W. Lull, eds.

Hough, Jack L. 1958. Geology of the Great Lakes. 313 p. Univ. Illinois Press, Urbana, Illinois.

Meyboom, P. 1967. Groundwater studies in the Assiniboine River drainage basin. U.S. Geol. Surv., Can. Bull., 139 p.

Stallman, R. W. 1956. Numerical analysis of regional water levels to define aquifer hydrology. A.G.U. Trans. 37:451-460.

Thornthwaite, C. W., and J. R. Mather. 1957. Instruction and tables for computing potential evapotranspiration and the water balance. Drexel Inst. Tech., Publ. Climatology 10(3):311 p.

Urie, Dean H. 1966. Influence of forest cover on groundwater recharge, timing and use. *In* Int. forest hydrology Symp. Proc. p. 313-324. Pennsylvania State Univ.

Urie, Dean H. 1971. Estimated groundwater yield following strip-cutting in pine plantations. Water Resour. Res. 7(6):1497-1510.

Velz, Clarence J., and John H. Gannon. 1960. Drought flow of Michigan streams. 771 p. Univ. Michigan, in cooperation with Michigan Water Resour. Comm., Lansing, Michigan.

Weeks, E. P., and M. L. Sorey. 1973. Use of finite-difference arrays of observation wells to estimate evapotranspiration from groundwater in the Arkansas River Valley, Colorado. U.S. Geol. Surv., Water-Supply Pap. 2029-C, 27 p.

White, Walter N. 1932. A method of estimating groundwater supplies based on discharge of plants and evaporation from soil. U.S. Geol. Surv., Water-Supply Pap. 659-A, 105 p.

★U. S. GOVERNMENT PRINTING OFFICE: 1978--767876/74 REGION NO. 6

Urie, Dean H.
1977. Ground water differences on pine and hardwood forests of the Udell Experimental Forest in Michigan. USDA For. Serv. Res. Pap. NC-145, 12 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

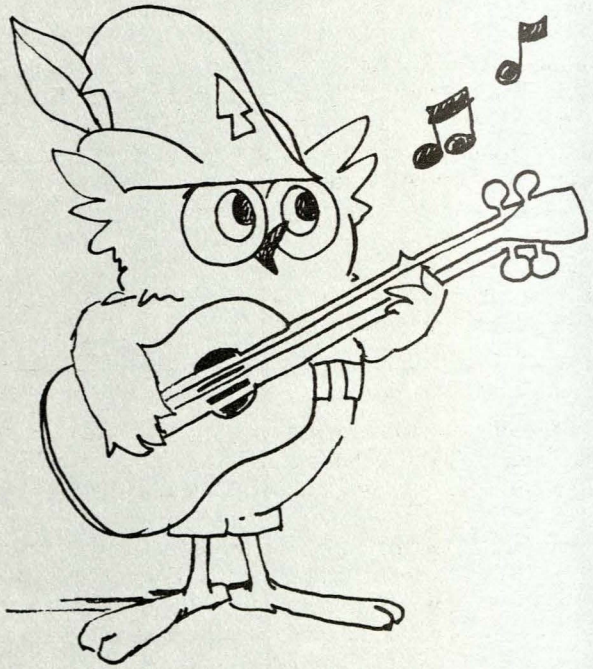
Ground water recharge under hardwood and pine forests was measured from 1962 to 1971 on the Udell Experimental Forest in Michigan. Hardwood forests produced more net ground water than pine forests by an average of 50 and 100 mm/year, using two methods of analysis. Shallow water-table lands yield 80 to 100 mm/year less water than deep, well-drained sands. Water yield decreased the most between drainage classifications of pine plantations.

OXFORD: 114.129:116.25(774). KEY WORDS: forest influences, water budgets, evapotranspiration.

Urie, Dean H.
1977. Ground water differences on pine and hardwood forests of the Udell Experimental Forest in Michigan. USDA For. Serv. Res. Pap. NC-145, 12 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Ground water recharge under hardwood and pine forests was measured from 1962 to 1971 on the Udell Experimental Forest in Michigan. Hardwood forests produced more net ground water than pine forests by an average of 50 and 100 mm/year, using two methods of analysis. Shallow water-table lands yield 80 to 100 mm/year less water than deep, well-drained sands. Water yield decreased the most between drainage classifications of pine plantations.

OXFORD: 114.129:116.25(774). KEY WORDS: forest influences, water budgets, evapotranspiration.



Sing along with Woodsy and help stop pollution.